CHAPTER 6

Implications of Soil Tillage for Weed Communities

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CONTENTS

6.1 INTRODUCTION

Weeds are significant in agroecosystems for two reasons. First, they can convert solar radiation into biomass. In this function, the wild vegetation in a field contributes to the energy budget of an agroecosystem; this energy is indispensable for life above as well as below the soil surface. Second, weeds are competitors of those plants deliberately grown to produce commodities for human use—agricultural crops. Both crops and weeds exploit the limited resources at a site, and therefore the impact of weeds on crops is largely determined by the type and intensity of interference with crop plants. If the competition remains without effects on the anticipated yields (in the current and future seasons), weeds are unlikely to cause real damage to crops or losses for the farm. Under such conditions the wild vegetation may even perform beneficial functions for agroecosystems.

Only emerged weed plants compete for the main resources and not dormant seeds or rhizomes. Consequently, established weed populations exert competition pressure on associated plant communities, including crops. Effects of soil tillage on weed and crop seeds have been addressed in a previous chapter in this book. Whether and how soil management may affect arable weed communities is the core subject of this chapter. Generally, however, it is important to emphasize that, independent of tillage practices, weeds are affected primarily by the specific site conditions, including the farmer's weed management strategies.

6.2 BACKGROUND OF WEED/CROP ASSOCIATIONS

Weeds are commonly defined as plants in the wrong place.[1] The "place" in this context refers to the field, the garden, the orchard, etc., where the "desired" plants—mostly crops—are commonly grown. This definition suggests that the strategic target should be the weed-free field, weed-free farm, or even the weed-free environment. The word *wrong* in the definition reflects the negative impacts of the wild vegetation on growing crops in spatial terms because of competition, transmission of pests and pathogens. Weeds result in monetary losses due to reduced crop quantity and quality.[2] Rademacher[2] strongly underscored the economic aspect of weed effects as he classified weeds as "undesired" plants in a field causing more damage than profits. Weeds may also hamper crop development, resulting in yield losses.[3] In addition, the presence of some weed species may be sufficient to reduce the efficiency of crop harvesting, contaminate produce, or aggravate storage or

processing steps. Cleaver (*Galium aparine*), for instance, is a well known climbing weed species in Europe. This nitrophilous weed not only competes for nutrients and water but can also block the combine at harvest time. Remaining cleaver (green) seeds in grain containers elevate humidity, encouraging pathogens and pests in grain stores and silos. Furthermore, cleaver-contaminated cereal grains cannot be sold as certified seeds due to legal seed purity regulations. No matter how weeds impact crops, their ultimate effects on farms will be of an economic nature. Increasing weed-related losses deteriorate farm economics and consequently net revenues.

Net margin is an economic parameter that describes the profits achievable after the variable production costs of a crop, including expenses for weed control, have been subtracted. The difference in net margins between "weedy" and "weeded" crop stands reflects crop losses and is an expression of the monetary value attributed to a weed infestation. Accordingly, *harmful* in economic terms means a significant reduction of net margins. Weed infestation incidence is one of many factors influencing yield loss. While there can be insignificant levels of weed infestations, control measures must be imposed on significant levels of weed infestations if economic losses are to be avoided. The principle of the economic threshold has been extremely helpful for decision making in weed control.[4–8] By definition, wild plants with no impacts on crop net margins are not or should not be considered weeds; although this is rarely the case,[9] weed infestation with no relevance for farm economics should not be even classified as weeds.

Weed species with the greatest potential to cause economic losses are mostly adapted to arable field environments such as site climatic features, crop rotation, fertilizer supply, etc. These species are distinguished by effective survival strategies, with particular regard to their reproduction rates and competitiveness. Adapted weed species are likely to resist soil cultivation, suppressive crop effects, and even herbicide treatments. They are "survivors" of selection pressure created by farming practices and are often difficult to control.[10] In contrast, wild plant species with low adaptation potential can hardly maintain significant populations under arable farming conditions. The life cycles of some wild plant species require longer time spans to reproduce and cannot shed seeds before crop harvest. These wild plant species are associated with the field flora as they disperse from nearby habitats. Endangered species commonly encounter adverse survival conditions on arable land[11–13] and as endangered arable plants are not capable of survival or high rates of reproduction under modern farming practices and emerging cropping technologies, which limits their survival. Soil tillage is one of many farming practices that exert selection pressure on wild vegetation. Tillage affects soil structure, with far-reaching implications for weed seed banks, mineralization processes, crop growth, etc. Weeds are affected by tillage both directly and indirectly.

Soil tillage systems can be divided into two main types according to their primary effects on the soil layer arrangement in the soil profile. These are inversion and noninversion tillage types. The moldboard plow inverts topsoil and moves it, along with weeds and other organic residues, into deeper soil layers. The biota of upper soil layers then becomes a part of the subsoil environment. By contrast, weed seeds of former deep layers are transported up into near-surface layers. Noninversion tillage

can be achieved using a variety of technologies. The soil profile is either tine-loosened without inversion (e.g., Dutzi System) or remains entirely undisturbed except by drilling furrows, e.g., no-tillage or direct drilling. Under noninversion tillage weed propagules largely remain in the same positions in the soil profile as before intervention. This distinction of tillage systems has far-reaching implications not only for weed germination but also for the whole soil environment. How weed populations are affected by the different tillage systems will be the subject of this chapter.

6.3 PERFORMANCE OF ANNUAL WEEDS UNDER DIFFERENT TILLAGE REGIMES

Composition and abundance of weeds are functions of interacting environmental and anthropogenic factors. In addition to tillage practices, crop species, crop rotation, fertilizer supply and control measures are determinants for weeds. Weed communities are simply closely associated with the farming system and the possible effects of plowing on weeds for example, can hardly be considered in isolation nor within limited time scales. Short term cultivation studies are useful to verify single aspects, but they are unlikely however, to provide the essential data on community shifts.

Tillage research has focused on assessing tillage-related crop production requirements rather than implications of tillage on weed communities. The greatest emphasis is devoted to erosion control and soil hydrological, structural, and nutritional properties under different tillage technologies.[14–19] Serious problems of land degradation, severe soil erosion, and loss of soil fertility are among the many effects attributed to intensive plowing tillage. Recently, soil tillage has also received increasing interest because of its potential influence on global climate changes and CO_2 and carbon sequestration.[20–23] However, during recent decades, the effects of noninversion tillage systems on weed management have become increasingly evident. Even though tillage is considered a key factor affecting weed populations, along with direct control measures, nutrient supply, soil pH, and sowing date,[24] replacing traditional plowing by alternative soil cultivation methods is reported to induce shifts in weed communities. In some cropping systems, tillage-related weed problems may set limits for the adoption of tillage systems.[16,17,25,26] This applies to a wide range of crop species, such as corn, soybeans, grain cereals, oilseed rape, sugar beets, sunflowers, peas, faba beans, and cotton, regardless of climate zones. In the majority of research conducted, climate and soil and cropping systems are identified as the main factors affecting agricultural productivity. Whereas soil tillage,[15,27–30] soil cover,[31,32] and crop sequences are acknowledged as key components affecting system efficiency. Therefore, sustaining productivity requires a careful integration of these components. In launching integrated systems, it is essential to identify the agronomic objectives of soil tillage, known as the primary tillage objectives. These are often reported to be guided by the removal of surface crop residues, seedbed preparation, soil aeration, weed control, and improvement of water infiltration. Different tillage concepts can meet these objectives, including plowing and noninversion tillage techniques.

6.3.1 The Plowing Tillage Concept

For many centuries the main objectives of soil cultivation were achieved by annual plowing (see Chapter 1 for details), described as *conventional tillage*. The most widely used implement was the moldboard plow. This was a simple, animal-driven wooden tool, and nowadays it is a heavy-duty machine that requires substantial tractor power. The plow cuts and turns topsoil at various depths, typically between 15 and 35 cm. In the temperate regions of Europe, the common cultivation practice is to plow in late summer or early autumn, after disking or cultivating the stubble. One or two harrow passes follow before drilling or planting the next crop.

6.3.2 Noninversion Tillage

Different technologies associated with no-plow tillage are subsumed under this heading; however, the common feature among these technologies is the deliberate banning of soil inversion. Soil layers are maintained in their natural positions within the soil profile, leaving surface crop residues on or in the topsoil. Based on the amount of organic residues left on the soil surface and the extent of soil loosening, the following tillage concepts are known:

6.3.2.1 No-Tillage Approach

In this approach, the soil is left undisturbed between harvest of the previous crop until the planting of the next crop, except for strips up to one third of the row width.[33–35] Planting is accomplished through the use of row openers, coulters, row cleaners, in-row disks, or in-row rototillers. The system is completely locked into a weed-management strategy involving the use of herbicide treatments since alternative weed-control options are not feasible (e.g., mechanical weeding).

6.3.2.2 Conservation Tillage

This is any tillage and planting system that induces more soil disturbance than the no-tillage approach and allows for at least 30% of the soil surface to be covered with crop residues after planting as an erosion-control measure. In the case of wind erosion, the definition requires keeping the equivalent of 1100 kg/ha of flat, small grain residues equivalent on the soil surface during the entire crucial wind-erosion periods.[36]

6.4 WEED DYNAMICS UNDER TILLAGE IMPACTS

The reproductive rate of a weed species is the most important determinant of the size of subsequent weed populations. Most annual weed species are characterized as r-strategists and have the potential to produce sufficient progeny to compensate for very high potential losses during their entire life cycle, with various kinds of

interferences.[37–41] This strategy makes it possible to maintain soil seed banks at levels that secure survival of the species. Perennial weeds, in contrast, use different reproduction strategies. Depending on the requirement of the species, the response to tillage type will differ;[42,43] however, remaining components of the farming systems may have even greater effects on weed populations than the tillage. Tillage-associated measures such as crop species or fertilizer amendments may mask or even suppress weed species' responses to a tillage regime. This is why the associated measures of crop management should receive particular attention when tillage effects on weeds are being appraised.

6.4.1 Responses of Annual Grass Weeds to Tillage Regimes

Grass species (Gramineacae) are widely spread as weeds in both arable crops and grassland. In the temperate agricultural zone of Europe, (e.g., United Kingdom, Scandinavia, and Germany), grass weeds have become the dominant species at many different cropping sites[38,44–49] following changes away from inversion tillage.

In studies of tillage regimes and sowing dates in an oilseed rape–winter wheat–corn–spring barley rotation, Amman[50] obtained significantly higher grass weed densities in noninversion compared to plowed treatments. At the beginning of these studies, 45% of the viable seeds (on average 450–6400 seeds/m^2) were blackgrass (*Alopecurus myosuroides*). Moldboard plow (20 cm working depth) was contrasted against a noninversion cultivation treatment using cultivator, rotary digger, or rotovator, at both early and late intervention dates. All other husbandry measures matched common standards. The density of *A. mysosuriodes* was highest in oilseed rape in the first year, gradually declining in the following winter wheat, corn, and spring barley rotations, respectively. The lower grass weed density was often associated with late sowing when compared to early drilling. In this case, such a germination pattern of *A. mysosuriodes* may result in declines in subsequent populations. Apparently, more germinated seedlings were destroyed during seedbed preparation for late drilling, whereas the counterparts in the early planting treatment escaped mechanical damage. In addition, the late soil preparation adversely affected the tillering rate, independent of the tillage regime practiced.

While *A. mysosuriodes* is a species adapted to noninversion tillage approaches, it is possible to manipulate its population dynamics upwards or downwards by exploiting the sowing date effects through adjustment of the crop rotation. This option, however, is hardly possible in rotations dominated by winter crops. Continuous monocultures of winter wheat result in a build-up of blackgrass populations.[51] In a study of the interactive effects of tillage (tillage treatments including annual plowing, alternating plow/broadshare cultivator [Dutzi system] and pure cultivator tillage), rotation, and weed control, the highest densities were assessed in winter wheat monoculture of the cultivated plots with no weed control. The survival of the weed was enhanced because seedling losses (through seedbed preparation) and herbicide treatments were eliminated. The rate of increase, expressed as the tillering ratio, was significantly lower as crop rotation was diversified (Figure 6.1). Despite

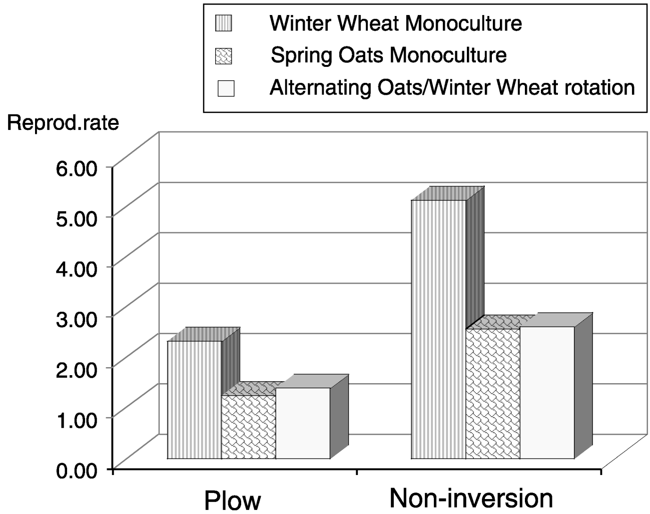

Figure 6.1 Reproduction rate (number of tillers/pl.) of *A. mysosuriodes* as affected by soil tillage and crop rotation. (Modified from Knab and Hurle, 1988.)

the higher densities in the noninversion tillage treatments, the authors concluded that crop rotation in itself was insufficient to avoid population increases of this weed.

Schreiber[52] revealed comparable effects of tillage/rotation interactions on Giant Foxtail (*Setaria faberi*) in the U.S. Corn monocultures were contrasted against corn rotated with soybean and corn following wheat in a soybean–wheat–corn rotation. Moldboard plow, chiseling, and no-tillage systems were also compared. The majority of *S. faberi* seeds were recovered in the topsoil of the no-tillage treatments of monoculture corn. Crop rotation significantly reduced *S. faberi* populations, with maximum reduction in the soybean–wheat–corn rotation under all tillage systems. There were no differences between the moderate and maximum weed-management levels. Corn yields showed that weed-management levels above the minimum were *not* justified regardless of the tillage system and crop rotation; higher weed densities did not necessarily require more intensive weed control. Other U.S.-based investigations on tillage effects provide supporting data. Buhler[53] compared effects of conventional tillage with the chisel plow, ridge tillage, or no-tillage systems in corn (*Zea mays*) on the population dynamics and control of green foxtail (*Setaria viridis*) in a corn monoculture, with and without irrigation. The green foxtail is a summer annual grass weed species of the same family (*Poaceae*) and is widely spread throughout northern California. The results of this study showed that weed densities were higher in chisel plow and no-tillage systems than in conventional tillage systems and were lowest under ridge tillage. However, it was not the plowing alone that affected the weed density, but the combination with other farming practices.

The dynamics of the soil seedbank seems to play a key role in long-term population trends of grass weeds. Field studies on wild oats (*Avena fatua* L.) in

spring barley, aiming to contrast the effects of plowing, tine cultivation, and direct drilling (no-tillage)[54] on the survival of soil seed stocks, clearly indicated the expected population trends. Wild oat seeds were introduced at a known density and viability into all three tillage treatments and at two different depths in the direct-drilling treatment. The barley crop was cut and removed for arable silage to prevent weeds from shedding seeds. Tine cultivation and direct drilling resulted in nearly four times as many seedlings as the plowing treatment in the season after seeds had set. Thus, there is a risk of rapid build-up of wild oats in the reduced-tillage treatments unless effective control measures are in place. Replowing a year later brought dormant seeds to the surface, resulting in more seedlings in the crops with the plowing treatment. Under noninversion tillage regimes, wild oat seeds in deep soil layers were considered insignificant for the population dynamic of this grass weed species, as they are likely to lose viability. This strategy of controlling emerged weeds and preventing shedding and seed return is supported by Roberts.[55,56]

Banning plowing, however, may enhance the populations of other weed species. The annual grass weed barren brome (*Bromus sterilis*) (also called sterile brome) is reported to survive and reproduce best in undisturbed soil conditions.[57–63] *B. sterilis* is an annual weed, occasionally biennial but rarely perennial, and often found on field margins, road verges, and tracks. The seeds have little innate dormancy, are shed from June to August, and germinate mostly in late summer and early autumn, provided that soil moisture is adequate.[64] The short lifetime of buried seeds makes this species susceptible to plow tillage.[65–67] Brome seedlings do not have the ability to emerge from a depth in excess of 13 cm.[68,69] The mortality of seeds buried even in a single year is sufficient to prevent a population increase. The potential rate of population increase of this species is reduced with increasing depths of seed burial.[61] Therefore, this weed can be managed effectively by adjustment of crop rotation and appropriate management of field margins and headlands.[44,48,70]

Studies of silky bent grass (*Apera spica-venti* L.) in Germany showed a different response pattern to tillage. Pallut and Bennewitz[71] found no significant differences in either weed biomass, density, or grain between plowing and noninversion tillage treatments in their long-term investigations in a winter cereals–potatoes/corn crop rotation. The observed tillage/rotation interaction indicates that *A. spica-venti* populations can be managed effectively under noninversion tillage. Population losses were obviously sufficiently high to compensate for tillage effects on weed density. This emphasizes the importance of the other husbandry practices associated with tillage system for prevalence of a given weed species.

As mentioned earlier, the intrinsic seed properties may greatly influence the specific response of a weed species to tillage regime. Changing seed position within the soil profile alters the microhabitat, with direct implications for both dormancy and viability of weed seeds. As a result, shifts in composition of the weed flora occur.[44,72] Enhancement of dormancy would support seed conservation, whereas seed emergence, in contrast, depletes seed stocks in the soil. *A. fatua* seeds buried at different depths have different survival rates, with survival being higher in deeper soil layers (conservation) than in the topsoil.[81] In contrast, *B. sterilis* seeds failed to emerge from deeper layers. Both examples demonstrate that the innate features of the weed species qualify its responses to reduced-tillage practices.

6.4.2 Responses of Annual Dicot Weeds

Effects of tillage on weed communities are not restricted to grass weed species only. Soil cultivation also affects broad-leaved species. Again, the type and intensity of tillage-based responses differ widely in relation to the involved weed species. Noninversion tillage is reported to exert positive, adverse, or no effects on dicotyledonous weed populations in many climatic zones.[49]

Banning plowing has contributed to substantial increases in abundance of *Taraxacum officinale* Weber, whereas, by contrast, populations of *Sinapis arvensis* L., *Raphanus raphanistrum* L., and *Polygonum aviculare* L. declined with decreased cultivation intensity.[46] In this study, germination/population density of *Stellaria media, Hercleum sphondylium* L., *Papaver rhoeas* L., *Mysotis arvensis* (L.), *Fumaria officinalis, Polygonum aviculare*, and *Aethusa cynapium* L. were enhanced by either tine cultivation or plowing, whereas *Anthriscus sylvestris* (L.), *Galium aparine*, *Lamium amplexicaule* L., *P. convolvulus*, *Senccio vulgaris* L., *Sinapis arvensis*, and *Sonchus spp*. L. did not show consistent responses to any of the tested tillage regimes. Varying responses to tillage at the species level were also reported in several other weed studies.[10,74–76] Like grass weeds, broad-leaved species are also affected by the combination of tillage with other husbandry measures. Cover crop, for instance, may determine development trends in weed communities under minimal tillage regimes. Schilling[77] verified the impacts by a tillage/cover crop combination in post-cereal fallow on weed incidence in the following sugar beet crop in Germany. Tillage was performed either with moldboard plow or noninversion tillage. Different cover-crop species were tested in these studies. *Fallopia convolvulus*, *Galium aparine, Chenopodium album*, and *Polygonum spp.*, along with volunteer cereal, were the prevailing weed species at the experimental site. Results confirmed that weed densities were lower in the plow treatment compared to noninversion plots. This applied in particular to the predominant weed species independent of monitoring date and developmental stage of the sugar beet crop. However, there was a significant weed (and volunteer) control effect by the green manure crop, with substantial suppression of weed biomass.

The significance of the observed effects is not limited to the annual cost savings in weed control but encompasses the long-term effects on the seed bank. Supporting results were obtained with other crop rotations and in varying climatic zones. Teasdale, Beste, and Potts[76] demonstrated significant tillage by cover crop by year interactions in the U.S. In four consecutive years within the no-tillage treatment, rye, or hairy vetch grown as cover crops reduced total weed density by an average of 78% compared to treatments without cover crop. In the no-tillage treatment, total weed density increased after 1 year, compared with 2 years under conventional tillage. Only the common lambsquarters (*Chenopodium album* L.) occurred in higher numbers in the no-tillage plots, and even here no difference was detected in total weed biomass between tillage treatments. The cover crop produced in these studies had a much higher effect on weeds under no-tillage treatments compared to the plow treatments. Pohlan and Borgman[78] recorded even lower weed densities in the sugar beet crops after an overwintering cover crop within the noninversion tillage treatments. The effects of cover crops on weeds can obviously be extended to include

other crops in varying rotations. Fisk et al.[79] recorded a reduction in the density of annual weeds varying between 41 and 78% in a direct-drilled corn crop in Michigan, USA. Different species of cover crops exerted different effects on weed dry weight in this study.

Garbe[74] came to different conclusions as he compared the combined effects of tillage and cover crop in previous fallow on weed infestation in sugar beet crop. Two tillage systems (noninversion and plow) and a number of cover crop species were tested at six growing sites with dissimilar weed communities that included *Capsella bursa-pastoris* Med., *Chenopodium album* L., *G. aparine* L., *L. purpureum* L., *L. amplexicaule, Matricaria chamomilla* L., *Myosotis arvensis* L., Solanum nigrum L., *Stellaria media* Vill., *Thlaspi arvense* L., *Viola arvensis* Murray, *Alopecurus myosuroides* Huds., and *Poa annua* L. *Veronica persica* Poiret, *Sonchus asper* Hill, *Fallopia convolvulus* L. Weed and volunteer densities were higher in the tine-cultivated treatments compared to plow treatments. The range of the observed differences varied widely among sites and weed species. The cover crop (mustard) suppressed weed density, but levels were different from those reported by Teasdale, Beste, and Potts[76] due to site features and weed spectra. *Matricaria* spp. and *Thlaspi* spp—considered to be poor competitors—were more effectively controlled by the cover crop compared to *Galium* spp. or *Viola* spp., which are reported to resist catch crop competition effectively. However, it is worth noting that weeds were successfully controlled with the recommended minimum herbicide treatments at all study sites. Even though cover crops suppress weeds over winter, they are believed to exert adverse effects on sugar beet yields. This was not the case at any of the six study sites when compared with the plowing treatment without cover crops. Size and composition of the weed population at a given site tended to have a greater effect on yield than either tillage or cover crop.

Biomass is an indicative parameter for the reproduction potential of plant species. Weed biomass is a function of competition from the present weed community and the crop grown. Firbank[80] adopted the definition of Begon, Harper, and Townsend[81] describing competition as the interaction between individuals brought about by a shared requirement for a resource in limited supply and leading to a reduction in the survivorship, growth, or reproduction of the individual concerned. Since competition operates at a local scale, available resources at the site, in particular nutrients, water, and solar radiation, are common targets of such competition. Implications of competition to crop growth and yield have been the subject of various studies in weed research.[80–86] Nutrient availability in soil is reported to change due to tillage regime and consequently affect crop–weed interactions (see Chapter 4 for further details). Therefore, tillage effects on competition for nutrients and water can only be of an indirect nature.

Wild plants may stimulate microbes and subsequently their own nutrient supply.[87] However, the response of weed species to nutrient amendments depends on the potential of the species involved to exploit this resource. Root architecture, ideotypes of the weed species, soil type, and moisture are some of the important factors. Nitrophilous species, such as *Chenopodium album L.* and *G. aparine,* are reported to respond to nitrogen inputs regardless of the tillage regime.[10] The same has been

found for phosphorus and potassium fertilizers. The uptake pattern greatly determines the exploitation level of applied fertilizers by weeds. On the other hand, fertilizers supplied to a crop commonly cover only a part of the total nutrients needed. The other, larger, part originates from soil organic pools. Therefore, the tillage system should address the requirements of nutrient management, taking into account the spatial and temporal scale of the nutrient supply to harmonize with crop uptake peaks. In row crops, band application of nitrogen fertilizers in the rows during drilling or immediately thereafter is likely to reduce weed biomass. In sugar beet experiments at Lautenbach, Germany, both fresh and dry weight of weeds—mainly *Thlaspi arvense* L., *L. purpureum* L., *L. amplexicaule, Veronica persica* Poiret, *Sonchus asper* Hill, *G.aparine* L., *Myosotis arvensis* L., *Stellaria media* Vill., *Matricaria chamomilla* L., *Chenopodium album* L., *Fallopia convolvulus* L., and *Poa annua* L.—at the row-closure stage were significantly reduced in five consecutive trials when fertilizers were applied in the crop rows only (Figure 6.2).

In addition to the partitioning and placement of fertilizers, the chemical composition and mode of action can affect weed communities in crop stands. Slow-release N fertilizers[88–90] are appropriate to minimize nitrogen losses, improve efficacy, and adversely affect weed growth. Ammonium nitrate fertilizers with nitrification inhibitors (e.g., dicyandiamide) are known to release the nutrient slowly, maintaining a longer availability through the NH4 fraction of the commercial product. This release mechanism contributed to a better synchronization between N offer and uptake.[88] Sugar beet crops yielded the same as with quick-acting fertilizers in five consecutive years at Lautenbach, Germany.

Row spacing[91] and in-row-applied fertilizers have adversely affected weed development, without significant effects on yields of the sugar beet crops.[92] The integration of an adjusted fertilizer supply with weed control tends to be an efficient tool for manipulating weed infestation, particularly under noninversion tillage conditions. Such tuned nutrient management may support the integration of nonherbicidal weed

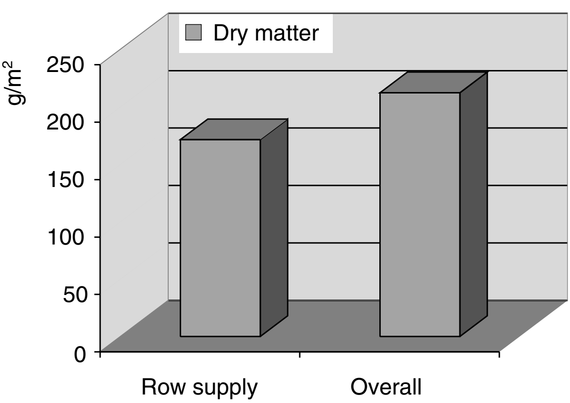

Figure 6.2 Effects of fertilizer row application on weed biomass in sugar beet crop in average of five consecutive trials at Lautenbach, Germany.

control while helping to minimize nonpoint environmental pollution. Work by Aleman[93] in Nicaragua, comparing different weed-control strategies (mulching, mechanical, and chemical) under three tillage regimes (no-tillage, minimum tillage, and moldboard plowing) in phaseolus beans following corn strongly support this approach. Minimum tillage outyielded both no-tillage and plow treatments in the range of 10–15%, while bean yields responded better to combined mechanical and chemical (herbicide) control than mulching in the no-tillage and minimum-tillage plots. He concluded that the combination of mechanical and chemical weed control would be sufficient in both tillage treatments. Other technologies, such as biological control, exist that should be considered part of an integrated weed-management program. There are an increasing number of bioherbicides that have proven effective against some weed species.[94–96] Despite intensive research efforts, bioherbicides are still of limited use, but this idea continues to receive considerable attention because of various environmental concerns of conventional weed management, especially with regard to water pollution.

Chemical weed control is well known as a very effective method in manipulating weed communities in both conventional and noninversion tillage systems. Large inventories in weed research clearly document how the herbicide era of former decades fundamentally changed entire farming strategies.[97–99] The available active ingredients range from high selective compounds to nonselective herbicides and cover a wide range of uses like cropped and noncropped areas and dry and aquatic environments. Use of herbicides in arable farming systems became almost indispensable as labor power per farm declined, relative wages increased, and cost-effectiveness improved. While the appraisal of herbicide effects on weeds of arable crops is not the focus of this chapter, the significance of herbicides for both conservation and conventional tillage systems at present and in times to come must be reemphasized.[100,101]

The effect of soil cultivation on weeds alone is insufficient to explain weed population dynamics without considering the interactions with other farming measures. This is particularly important in long-term forecasting models for weed infestations.[80] Moreover, factorial research approaches are unlikely to meet the demands for data. System research concepts seem to be the most appropriate scientific tracks to follow,[102] and, indeed, this has been the foremost method of farming system research in Europe for over two decades.[103,104] A system approach based on noninversion tillage within an integrated farming system (IFS) was established at the arable farm (240 ha) of Lautenbach and contrasted against a conventional farming system (CFS) based on annual plowing (CFS).[92,105] The IFS comprises various farming components.[105,106] The design was based on six field pairs, simulating two farms of 36 ha each within the Lautenbach fields. Half of these field units were managed due to IFS guidelines, whereas the other six fields were farmed in accordance with current farming practices in the region. A package of husbandry techniques, including noninversion tillage, reduced agrochemical inputs, under-sowing (inter-cropping) or cover crops (green manures), and ecological infrastructure, were implemented on the IFS fields. This package was applied to all IFS fields, regardless of the grown crop. Cover crops were included in the CFS in a few exceptional years.

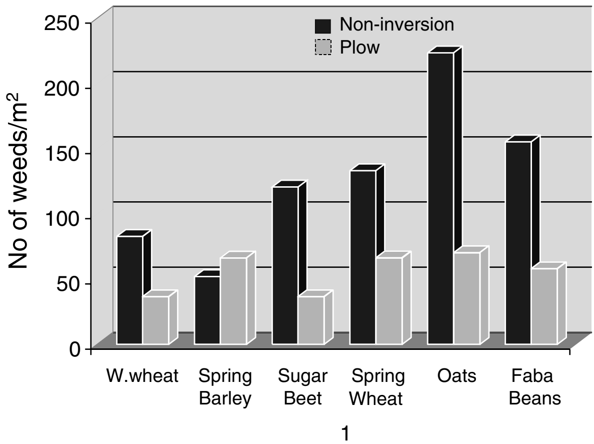

Figure 6.3 The precontrol weed infestation incidence (number/m^2), annually monitored on both unplowed—integrated farming system—and plowed conventional farming system—neighboring fields in average of 17 years (1978–1994) at Lautenbach, Germany. The database for average varied between 6 (spring barley) and 21 cases (winter wheat) due to cropping frequencies in the implemented crop rotation.

Gross margins and responses of a selected number of bioindicators were used to evaluate both farming systems. Weed populations were monitored regularly on all field units prior to weed control in these studies. Running both systems over 17 years provided a large number of scenarios and situations matching actual farming reality. Data from Lautenbach confirmed many of the results reported in this chapter. Incidence of weeds on the cropped areas was found to be higher for IFS than for CFS. The differences varied widely depending on the year, weather, crop, and weed species, but overall there was a clear tillage effect for all crop species grown. Figure 6.3 illustrates the average densities of both mono- and dicot weeds according to cropping frequencies.

Tillage effects on weed densities were evident through the entire research period. Only on single occasions, often induced by insufficient control treatments in previous years, were more weeds encountered on CFS fields. Differences in total weed densities were attributed to very few prevailing species. Shifts in weed communities were proved to be influenced more by year and tillage system than by crop species. In cool and wet springs, *Stellaria media* Vill. emerged in high numbers independent of the crops grown. *Convolvulus arvensis* dominated in a single field, *L. purpureum* L on another, whereas *G. aparine* L. occurred on one of the six CFS fields in extremely high numbers 2 years after an insufficient herbicide treatment in sugar beet. *Alopecurus myosuroides Huds.* and *Poa annua* L were the widespread grass weed species at the site, generally with higher densities on IFS fields, as reported in research elesewhere.

6.4.3 Responses of Perennial Weeds

The observed tillage effects are not restricted to annual species but include perennial weeds, both mono- and dicot. Field experiments involving zero, minimum, and conventional tillage in the U.S.[107] suggested that increased associations of perennial and annual grasses with zero tillage generally did not occur at the different sites. Crop volunteers and wind-dispersed weed species, by contrast, were most frequent in the no-plow treatments. Quackgrass (*Elytrigia repens* (L.) Nevski) was found to be moderately associated with either zero or minimum tillage treatments but showed no population increase in any of the tillage treatments or study sites. Tillage system may have an indirect effect on wind dispersed weed seeds, for example, the bunchgrass or foxtail barley (*Hordeum jubatum* L.), a perennial with wind-borne seeds, native in the study area. This weed was expected to establish in the no-tillage fields, but densities remained low despite a known association with the no-tillage system. Foxtail densities ranged from 105 to 702 plants/m^2 at one of the experimental sites but did not correlate with any tillage treatment during the period 1986–1988. These findings differ to some extent from other results (see, for example, References 108–111), presumably due to some other differing cropping and site features. The latter researchers concluded that higher infestation levels with both grass annuals and perennials were associated with no-tillage. In addition, other studies[112,113] stated that established weed plants can *only* be controlled by tillage. Results of tillage research in Europe showed similar trends. If the cultivation intensity is lower, the density of grass weed is higher, regardless of annual or perennial weed type.[114–117] Nalewaya[118] identified the major disadvantage of total no-till crop production to be the increase of perennial weeds, which could, preferentially, be controlled more effectively by application of nonselective herbicides on herbicide-tolerant crop cultivars.

Research inventories on perennials in arable crops suggest that dicot perennials commonly behave similar to grass weeds in relation to soil tillage. Derksen et al.[107] also investigated tillage impacts on Canada thistle (*Cirsium arvense* (L.) Scop.), sow thistle (*Sonchus arvesis* L.), dandelion (*Taraxacum officinale* (Weber), the biennual wormwood (*Artemisia biennis* Wild), and common groundsel (*Sencio vulgaris*) L. The association of these species with tillage system was classified as inconsistent. For instance, *S. arvesis* was associated with no-tillage at one study site but with the plow-treatment at the other site. In Greek studies with a wheat–vetch–cotton–barley rotation, the perennials *Malva sp.* and *Cynodon dactylon* prevailed from the second year of experimentation onwards in the no-tillage plots compared to minimum and conventional plowing treatments.[119] The often assumed adverse effects on crop yield potential was not evident.[3] The lack of consistent associations may be related to the varied selection pressure of the crop/herbicide rotations used, and this has been reported as most significant factor for weed survival rates.[43,111,120]

There are various reasons why expected yield responses to soil tillage are not consistent despite substantial tillage effects on weeds. This may be explained by the complexity of interacting factors at the growing site.[121]

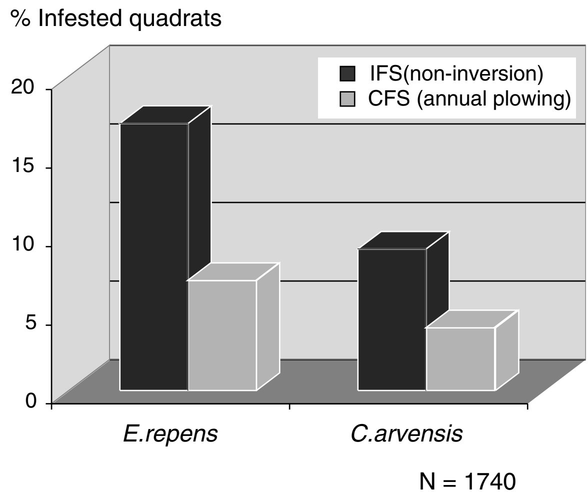

Figure 6.4 Infestation frequency for two perennial weed species at Lautenbach, Germany as they were monitored between 1977 and 1994 (20 × 0.5 m^2/plot/year, prior to weed control measures) under plowing and noninversion soil-management regimes.

Lack of population increase of perennial species may be attributed to different husbandry factors. Ehlers and Claupein[122] identified row spring crops as having substantial adverse effects on the Canadian thistle and quackgrass. The management strategies used (e.g., cover crop) are likely to reduce the potential of some perennials to reseed or to disperse below the surface. Mulched cover crops with a dense canopy have proved to suppress both germinating seeds and shoots of *E. repense* and regrowth of *C. arvense* from terrestrial rhizomes. Mulching has an evident control potential against perennial weeds, strongly supporting herbicide effects. In the aforementioned long-term research at Lautenbach, either mulching or shallow cultivation of the cover crop during winter frost periods had apparently prevented local perennial weeds from dominating on noninversion-tilled fields. Regular monitoring of *E. repens* (shoot density) over 17 years revealed slightly higher frequency in IFS fields compared to CFS fields (Figure 6.4.).[105,122]

To summarize, soil tillage can provoke significant shifts in weed communities of arable land. Depending on the longevity, fitness, and innate regulation potential of the involved weed species, a wide range of responses differing in type and intensity may occur. Species with similar habitat requirements showed comparable responses to soil tillage types. Grass weeds, for example, both annuals and perennials, tended to be more associated with no- and noninversion-tillage regimes. By contrast, broad-leaved weeds prevailed more under conventional-tillage environments. Consistent separation of weed species either in plowing or in noninversion-tillage environments was not evident. Among annual grass weeds, higher annual densities were observed, especially in monoculture with no or insufficient control interventions. Weed incidence in arable fields of tillage-adjusted crop rotations were generally less severe

and manageable without additional control treatments. Husbandry measures other than tillage had substantial effects on composition and abundance of weed communities. This applied in particular to crop rotation, cover crop, and effective use of weed-control measures including herbicides. In general, perennials tended to dominate under no-tillage systems, when environmental requirements were favorable. Crop yields tended to respond more to interactions between prevailing annual conditions, crop-management patterns, and soil tillage regime rather than to weed density alone.

6.4.4 Shifts in Weed Diversity as a Function of Tillage

The wild flora at a given site is strongly influenced by the prevailing climatic and habitat features. In undisturbed natural ecosystems, species composition of the indigenous vegetation is ultimately determined by the available resources at the site. Single species occupy spatial and temporal niches in the habitat according to their specific requirements. Species dominance and species successions are some of the ecosystem-related consequences. Changes of single habitat components, such as soil structure, nutrient supply, irrigation, or drainage, are likely to cause shifts in both species dominance and sequences, potentially leading to a different structure of the vegetation. In contrast to many natural ecosystems, flora of arable fields is exposed to constant periodical changes. A large number of environmental and agricultural factors interact with each other, creating selection pressure on the weed flora. Structural responses are well-documented aspects.[84,124–126] Koch and Hurle[84] reported a decline in perennial species as soil cultivation intensity, fertilization, and liming increased in Germany. Species like *Conringa orientalis, Caucalis lappula*, and *Adonis aestivalis* increasingly lost their habitats. Other former weeds, such as *Camelina spp*. in flax, have disappeared completely as their host crops were abandoned. The average loss of 30–40% of the initial number of weed species that occurred between 1940 and 1978 is attributed to the intensification of German agriculture.

In light of this, tillage effects on the diversity of weeds are unlikely to become evident soon after converting to another soil tillage system. Despite changing technologies, longer time spans are needed to identify consistent changes in weed communities. Interference through allelopathy, for example, requires several generations before effects become traceable. Variations in the mechanisms, direction, and magnitude of interactions between life history stages suggest that the current models of plant community structure, known to be largely based on exploitation competition, are inadequate for even simple annual plant communities.[40] Grasses are superior competitors to dicots at the emergence and survival stages and show higher emergence and survival regardless of the density. The observed numerical dominance of grass weeds in the reported studies strongly supports this interpretation. Independent of tillage system, the innate population dynamic features of weeds determine species shifts in the field community.

Nevertheless, based on the reviewed studies, noninversion tillage seems to produce clear effects on the species composition of weed communities, even though those effects are not always consistent. Major species shifts have been recorded for grass weeds rather than for dicot species. This was mainly the case for small seed grass

species, such as *A. mysosuriodes, Avena fatua*, of annuals *A. spica-venti, Setaria viridis, S. faberi, Bromus sterilis*, and perennial species *Elymus repens*. In contrast, dicot annuals showed a higher level of association with conventional tillage, e.g., *Polygonum convolvulus, Lamium aplexicaule, Vaccaria pyramidata* Medicus, *Chenopodium album* L., *Polygonum convolvulus* L., *Amaranthus blitoides* S. Wats., *Polygonum aviculare* L., and *Solanum triflorum* Nutt. This association applied to perennials *C. arvensis* and *T. officinale*. Furthermore, some studies indicate full association of a weed species with tillage regime. Buhler[53] reported that the horseweed (*Conyza Canadensis,* family Lamiaceae) occurred only under no-tillage treatment.

Shifts in plant communities are commonly indicated by diversity parameters.[127–132] These include mainly Shannon-Weiner H index, evenness E index, richness D index, and dominance C index, each showing strengths and weaknesses. The H-index is said to give higher weight to species of rather low density, whereas the D index overestimates the prevailing species. Based on their studies in corn no-tillage systems, Coffman and Frank[133] suggested that the continuous use of conservation (= noninversion) tillage may alter the composition of annual weed communities by the second or third year. Cardina et al.[134] recommended the techniques explicitly for indicating weed community shifts due to cultural measures. Bilalis et al.[119] used both D and H indices to verify impacts of three tillage regimes on shifts in weed spectra in a 3-year crop-rotation treatment in Greece. They concluded that the annual weed population showed a higher proportion of common species in the no-tillage system and a higher proportion of rare species in the moldboard plowing system. Surprisingly, both D and H indices for perennial weed species, mainly *Cynodon dactylon, Malva sp.*, and *Convolvulus arvensis*, were found to be higher in the plow treatment. These results are supported by other studies[132] using Shannon-Weiner H-index, richness D1 index, evenness E index, and dominance C index. They suggest that the tillage system did not exert shifts in the species composition of weed communities but altered the relative abundance of the present species (numerical response). In the Lautenbach studies, the diversity index—expressed as the average of three different fields—tended to be higher for IFS than for CFS.[135] Although densities were higher on the noninversion field, there was no significant difference in the diversity parameters. The ratio between the number of present species and the total weed density[136] indicates shifts in the dominance (Figure 6.5).

Despite annual fluctuations, the average diversity index H tended to be higher on the unplowed field of IFS compared to CFS. Reduced-tillage systems are likely to contribute to higher weed density and more diverse weed communities in arable fields.

6.5 FUNCTIONS OF WILD FLORA IN CROP/WEED ASSOCIATIONS

Many weed/agroecosystem studies document both beneficial and harmful effects of wild flora for a farming system independent of the soil tillage regime practiced. Adverse effects of noncrop vegetation in arable fields are commonly a function of the population density at a crucial crop-development stage. Most research devoted to this aspect has been conducted in economic threshold studies in weed control.[6,48,84,137]

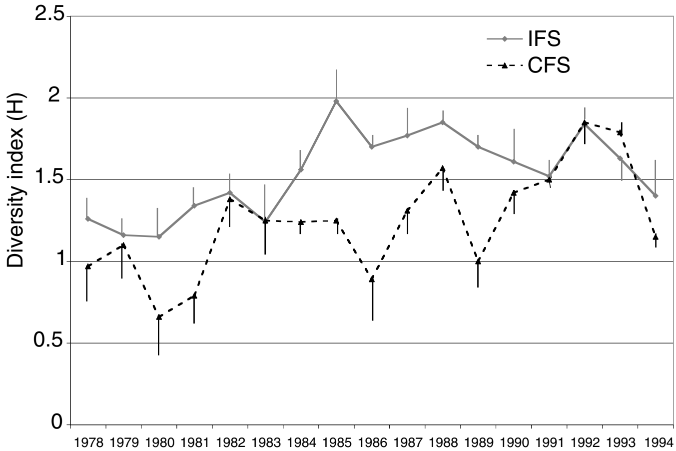

Figure 6.5 Shifts of the weed diversity index H (Schannon and Weaner, 1963)[136] based on annual weed monitoring on six field pairs of distinct soil tillage treatments over 17 years (1978–1994) at Lautenbach, Germany. (IFS = noninversion/CFS = annual plowing).

It is one of the guiding principles of the integrated pest management (IPM) concept.[4,105,138,139] Economic threshold is defined as the weed density at which the cost of control just equals the economic benefits to be gained as a result of control. Weed control at greater infestation levels would justify the control economically.[6,137] Weed density may be expressed as a numerical parameter (number or range threshold), soil cover index, or biomass weight at the crucial control times, determined mostly by susceptibility of weeds to control measures applied. The threshold may be applied in a rotational context.[140] The yield response of annual crops to weed infestation is a function of crop fitness, developmental stage, and competitiveness. Various researchers have measured crop responses over different periods of crop growth when weeds were allowed to grow together with the crop before weed removal, and over periods during which the crop was kept weed-free after sowing or emergence. Tolerating weed infestation during no-competition periods is classified as the *period threshold*.[141–144] In the corn crop, for example, the period between the six- and eight-leaf stage is the most critical for weed competition. Before and after this period corn crops are not adversely affected by weed competition. Wild flora present during the "safe" periods does not perform as a competitor and consequently is not classified as weed according to the definition given earlier. However, despite being innocuous, wild vegetation in a field interacts with crop in various ways, with different outcomes.

6.5.1 Noxious Weed Effects

A large number of publications addresses impacts of weeds on relevant crop criteria other than yield.[145] Weeds act as alternative host plants for crop pathogens, insects, and nematodes (e.g., References 37, 146–149). It is not the intention of this chapter to review the literature related to this topic but rather to underline the role

of weeds in cropping systems including tillage and consequently for agroecosystems. Grass weeds, in particular *A. myosuroides*, *Elymus repens, Poa annua, A. spica-venti, Avena fatua*, and *Bromus sterilis*, are known to host a number of fungus pathogens and viruses, affecting the epidemiology of crop diseases.[37,149] The carry-over of pathogen inoculum is particularly evident among viral diseases of annual crops.[150,151] *B. sterilis* and *E. repens* are reported to provide the initial inoculum for further infestation of crops. Dowe and Decker[147] reported that *Avena fatua* and *Elymus repens* can host oat cyst nematode (*Heterodera avenae*), while *Solanum nigrum, S. dulcamara*, and *Hyoscyamus niger* can host *Globodera rostochiensis*, the potato cyst nematode. *H. schachti*, the sugar beet cyst nematode, is known to have a wide host range including a larger number of dicot weeds like *Atriplex* spp., *Capsella bursa-pastoris* Med., *Chenopodium album* L., *Thlaspi arvensis, Stellaria media, Sinapis arvensis*, and *Polygonum persicaria.* Similar effects have been documented for insect pests.[152] As it is rarely practical to eradicate all site-adapted weed species, it is common to minimize harmful weed effects by tolerating an infestation below the threshold level. There are various crop-management practices that have adverse effects on weeds including adjusted fertilizer supply, cultivar choice, undersowing, cover crop, etc. The integration of such measures is a primary requirement in integrated farming systems.[6,106,138,139]

6.5.2 Beneficial Functions of Weeds

There is considerable research documenting beneficial effects of weeds in agroecosystems. Wild flora, especially in situations where yield is not compromised (e.g., off-cropping periods or on field margins)[11,153] is the subject of major studies.[154–156] In addition, effects of tillage should be considered in the context of the whole farming system, as they are of an indirect nature and may enhance or suppress weed species. Weeds are reported to be important in fueling food webs in soil ecosystems.[218] Key beneficial functions of weeds in arable agroecosystems are discussed in the following subsections.

6.5.2.1 Suppression of Other Weed Species (Allelopathy)

Within weed patches, neighboring plants of different species may affect the growth of individuals in different ways.[157–160] The mechanisms involved in such interactions between species and within the population of a single species are diverse in nature and mode of action. Competition and allelopathy are the main forms of interference describing the effects of one organism on another.[161] Few studies in weed research address effects of the allelopathy on seed germination of both crops and weeds (see Chapter 5). While competition between species or individuals is based on complete or partial depletion of at least one limiting resource common to the involved species or individuals, allelopathy is characterized by the release of biologically active chemical exudates, or allelochemicals,[162] by one species or individual and its uptake by another without detoxification or deactivation.[11,160,163] The worst weed species of the world are reported to have the highest allelopathic potential.[164,165] The effects of allelochemicals can be stimulatory or inhibitory for

other species. The classical example of striga (*Striga asiatica*), a parasitic species that feeds on roots of corn, millet, sunflower, rice, tomatoes, and a number of noncrop grasses, shows the potential of allelopathy in controlling injurious plant species. An effective allelochemical called strigol has been isolated from roots of cotton plants. Stimulating the germination of *S. asiatica* seeds in absence of host plant species can successfully control the crop parasite as a result of the released chemicals.[37] Chemical extracts from the rhizomes of the quackgrass *Elymus repens* (L) Gould are reported to inhibit seed germination of *Sinapis alba, Lepidium sativum, Amaranthus retroflex*us, and *Triticum aestivum*.[166] Similar effects have been observed for other Gramineae species. Other studies confirmed that crop residues of winter rye significantly reduced weed biomass in no-tillage fields.[167] Both rye crop residues and water extracts exert toxic effects on a number of plant species.

Marshall[45] studied the interference mechanism between sown grasses and growth of *E. repens* rhizome in England. He concluded that the rhizome growth from single-node fragments on plots sown with six perennial grasses was reduced by a factor of ten compared with initially bare plots. The location of shoot complexes of quackgrass after three seasons indicated that *Arrhenatherum elatius* and, to a lesser extent, *Agrostis stolonifera* or *Dactylis glomerata* prevented couch growth more than *Holcus lanatus* or *Poa trivialis*. A fertilizer treatment included in these experiments doubled rhizome growth. Although the allelopathic effects might have been involved, it is more likely that the ecological strategy of sending outer long rhizomes to form new plants (the Guerilla strategy) was competitively inferior to the "phalanx" strategy characterized by dense tuft and deep roots of *A. elatius.* Grass strips on field borders, independent of tillage regime, would help to prevent quackgrass from dispersal into crop fields.

6.5.2.2 Attraction of Crop Pests

There is a large inventory of associations of pest and beneficial arthropods with different weed species of arable crops.[154,168–171] The extreme dominance of the crop greatly facilitates host-finding by pests and the build-up of infestations. The invading pest species is attracted by various stimuli such as volatile odors, colors, semiochemicals, or combinations of these. The concentration and attractiveness of these compounds change as the host plants grow. Some species of wild flora seem to attract the same herbivores that are also known to threaten crops and so can mitigate, dilute, or even trap initial pest outbreaks. Whether or not the pests thereafter move across to the crop plants depends on their life cycle and reproduction rate. In any case, even a delay might be helpful, as the crop plants can grow larger and become more resistant to at least some pests. Such deflection of invading pests from crops has given rise to the use of intercropping as a pest-management option in arable cropping systems. At Lautenbach, Germany,[172] the deliberately delayed removal of weeds in sugar beet crops reduced both density and infestation incidence of the black aphid *Aphis fabae* in three consecutive years. Both colony size and infestation incidence were significantly reduced in the presence of weeds. *Pegomyia hyoscyami* (Panz.) incidence was, on average, 60% lower in the weedy stands of sugar beet crop

Figure 6.6 A Mayflower weed plant (*Matricaria chamomilla*) with attracted pest aphid (*Aphis fabae*) in a sugar beet crop, as observed on the unplowed fields of integrated farming system at Lautenbach, Germany in spring 1988. (Photo: El Titi).

compared to weed-free conditions. The canopy of Mayweed *Matricaria chamomilla* (Figure 6.6) was found to be most attractive to black aphid, whereas wireworm larvae (Eletridae, Coleoptera), mainly *Agriotes obscurus* L. and *A. lineatus* L., were highly aggregated on roots of the same weed species. In addition, the Compositae provides nutritional sources for aphid antagonists, e.g., Hoverflies (*Syrphidae*).[154,173,174]

In the Lautenbach studies, sugar beet seedlings adjacent to *Matricaria* plants remained undamaged.[172] Similar effects of weeds were observed for the slug *Deroceras reticulatum.*[176] Studies were also conducted to verify the effects of emerging weeds on seedling losses caused by millepedes (Diplopoda). From the eleven diplopod species, a single species, the spotted snake milliped *Blaniulus guttulatus* (Bosc.), was reported as a sugar beet pest under wet soil conditions. Germinating weeds significantly reduced the milliped infestation incidence on sugar beet compared with weed-free treatments, as was the case with wireworm infestations. The results are summarized as perceptual deviations of infestation incidence in weedy plots from the weed-free treatment (Figure 6.7).

Studies on subterranean springtails provide further examples for weed function in crop ecosystem. Ulber[175] studied weed effects on seedling damage of sugar beet caused by *Onychiurus fimatus* Gisin (Collembola/Insecta). In a choice trial, 18 arable weed species were offered as alternative food sources, together with sugar beet seedlings. The insects could choose between weeds and sugar beet. The results showed that, whenever weed seedlings were accessible, severity of seedling damage was reduced on sugar beet. In addition, there were different levels of preference for the different weed species. *Raphanus raphanistrum, Atriplex patula*, and *Avena fatua* were classified as attractive as sugar beet seedlings. These results suggested that post-emergence weed control may provide a valuable tool to exploit pest deflection effects of weeds in sugar beet crop. The availability of post-emergence herbicides strongly supports this “integrated” pest-management and weed-control option.

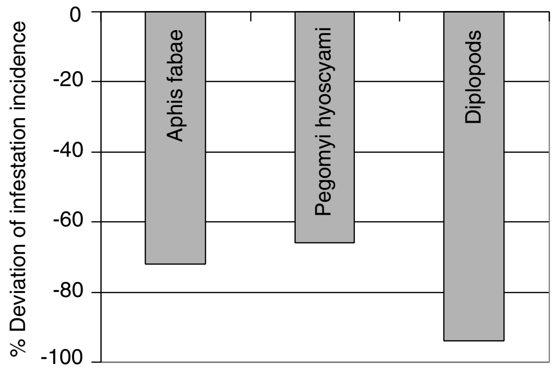

Figure 6.7 The percent deviation of infestation incidence for three main pest species in sugar beet crop in plots with retarded weed removal compared to weed-free treatment (weed-free = 100% line) in average of three successive years at Lautenbach, Germany. (0 infestation incidence in weed-free treatment.)

Fortunately, this has indeed become the standard weed-management strategy in German sugar beet cropping systems. Similar effects of weeds were proved for slug management in oilseed rape crops. At low slug incidence, *Stellaria media* and *Capsella bursa-pastoris* contributed to the enhancement of crop density.[176,177] In this function, weeds may obtain a different value, as noninversion tillage systems may enhance some faunal taxa, such as Collombola. These are only a few examples of weed effects on pest species; the interested reader is referred to a large inventory of entomological literature on this subject.[175,178–182]

6.5.2.3 Enhancement of Antagonistic Agents

Changes in soil structure greatly modify habitat features for many soil-dwelling organisms. Plowing results in the highest levels of soil disturbance. In contrast, no-tillage systems cause the least soil disruption. Apart from such direct effects of soil cultivation, tillage reveals many other indirect effects. Responses of beneficial species to soil tillage may result in shifts of pest–antagonist relationships in the soil ecosystem by interaction with field surrounding environments.[11,173,174] Predators and parasitoids are particularly important in integrated pest management approaches.[183,184] Epigeal arthropods are one of the well-studied faunal groups in arable land as they are directly exposed to tillage effects (see Chapter 11). Increased levels of weed ground cover tend to affect the abundance and activity of carabid and staphylinid beetles[245] and spiders.[185,188,189] Removal of weeds reduces the total arthropod biomass in crop by up to one third of the potential weight measured in weedy crop stands.[190] In the U.S., soil arthropod density was found to be consistently higher in weedy, no-tillage treatments than in other combinations of tillage and weed management.[191] The mere presence of weeds in the experimental plots resulted in higher arthropod densities regardless of the herbicide treatment applied. Data from Lautenbach, Germany strongly confirm these findings, as weedy plots resulted in higher pitfall catches of carabids and hymenopteraous parasitoids[192] (Figure 6.8).

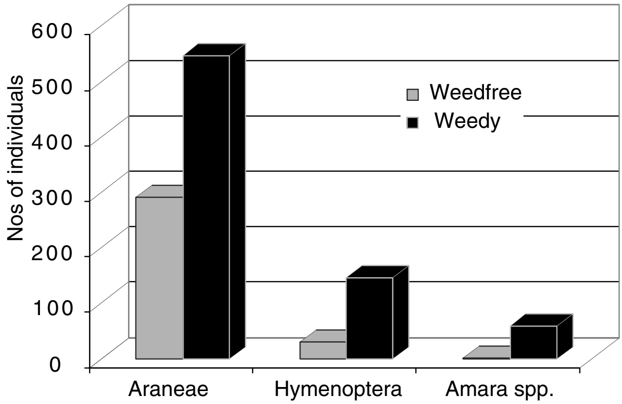

Figure 6.8 The total number of arthropods catches in pitfall traps within 5-month period in a winter wheat crop 1994 at Lautenbach, Germany. *Amara* spp. are known as potential feeders on weed seeds. (Modified from Bosch, 1986.)

The association of parasitoids with reduced or noninversion tillage may be explained either through shelter needs of these minute insects, nutritional mechanisms, or the association with specific hosts. Studies in Sweden on the pollen beetle (*Meligethes aeneus* Fb.) of oilseed rape were set up to compare effects of plowing on three hymenopteran parasitoids (*Phradis interstitialis, P. morionellus*, and *Tersilochus heterocerus*) known to attack larvae of the beetle.[193] Post-hibernation emergence of the parasitoids was found to be substantially lower compared to noninversion-tillage treatments in oilseed rape. It is widely assumed that such direct tillage effects are likely to be similar for many other topsoil resident antagonists.

Weeds provide the essential vegetarian diet that many antagonistic insect species require to reproduce. Pollen and nectar of wild flora that occur during periods when no alternative food sources are available, e.g., at the post-blossoming stage, are almost indispensable for survival of beneficial guilds. This seems to be particularly important for the minute hymenopterous parasitoids. Studies at Lautenbach explored the potential role of wild flora as a dietary source for beneficial insects using honeybees *Apis mellifera* (*Carnica*). These honeybees are known to have patterns of pollen collection similar to those of many other parasitoids and pollinators. Five hives of similar population size were installed at Lautenbach, with five other hives of the same structure placed at 5 km-distant arable enterprise.[194] Stored pollens in the stocks were analyzed and identified at the species level. Although the majority of the collected pollen was found to be of "cropped" plant species, the proportion of pollen of the local wild flora was much higher at the IFS noninversion-tillage site as compared to the other site. The proportion of wild species increased towards summer and autumn as the pollen availability from the crop decreased. This reemphasizes the significance of wild flowers for predators and parasites, in particular during times of crop-borne pollen shortage. This type of ecological interaction between wild flora of crop fields and association of antagonistic agents has received little attention in the traditional weed research, despite the significance of pollinators for crop yield.[154]

6.5.2.4 Runoff and Erosion Control

Soil cover has been repeatedly confirmed as an efficient tool to control runoff of soil water and soil water erosion.[16,20,32,195] The combination of a noninversion tillage, preferably no-tillage system, with a cover crop achieved the highest erosion-control levels in agricultural practice. Cover crops protect soil mainly during the crop-free periods, e.g., during fallows. Longer-lasting soil cover is likely to improve soil protection, especially at sites prone to erosion. The extension of soil cover duration offers more effective erosion control within row crops with slow seedling development, such as corn or sunflowers, at least until the row-closure stage. However, the option of maintaining a cover crop within interrows of the following crop may face serious agronomical constraints (mulching, growth control, etc). Grass strips in interrow spaces are also effective in erosion and runoff control, but perhaps these could be substituted by weed cover, at least until row closure. Although, reliable erosion assessment methods are available (see, for example, Reference 196), there is little data on the use of intercropping for erosion control.

6.6 CROP MANAGEMENT UNDER TILLAGE EFFECTS

6.6.1 Nutrient Management

Impacts of cultivation on weed communities can be highly affected by the fertilizer regime.[126,197,198] Therefore, fertilizer supply should be adjusted to the growth pattern of the prevailing species to suppress weed competition with the crop. However, the exploitation of nutrients from soil pools is definitely not restricted to crop plants only. Crop accompanying vegetation may also be effective in nutrient uptake. Previous crop volunteers and cover crops have been advocated as effective tools in preventing nitrate leaching.[199] Cover (= catch) crops are used as a legal tool in nutrient management, as they are recommended in water vulnerable regions.[200] For example, groundwater protection directives in southwest Germany[199] require a soil cover during the critical nitrate-leaching periods of the year; in addition, these directives forbid incorporation of organic manures during such time spans. The directives apply in particular to water-conservation zones. Accordingly, weeds and volunteers may continue to function as a "cover crop" over winter and contribute in this way to environmental safety. However, no quantitative data are available on nutrient uptake by weed communities and volunteers. Consequently, their efficiency in preventing NO_3 loss can hardly be evaluated quantatively. In general, allowing weeds to remain as a temporary soil cover is likely to support other leaching and runoff control measures.

The specific life cycle of some weed species may be consistent with such goals. *Thlaspi arvense* has a relatively short life cycle. This weed can exploit available nutrients (applied and soil mineralized) in much shorter time spans than the accompanying crop, revealing positive effects for host plants of different faunal groups[154] and preserving nutrients from being lost. In winter wheat, the weed population starts to decline prior to the wheat blossom stage. Field pennycress is of limited competition potential, rarely causing economic damage. At Lautenbach, weed canopy

breakdown was synchronous with the peak demand for nitrogen of winter wheat at grain filling. Although the phenomenon has not yet been quantified, this weed appears to function as a temporal nutrient carrier and may help minimize nutrient losses.

6.6.2 Weed Management in Conservation Tillage

There are many reasons why farmers adopt conservation-tillage practices. The destructive consequences of conventional tillage are increasingly contrasted against the beneficial results related to erosion control, humus content, soil physical properties, and the presence of beneficial organisms, among other effects. There is a worldwide change in tillage philosophy depending on specific farm constraints and economic pressures. Once a tillage system is adopted, farmers are locked into this pathway for a considerable time as long as any constraints can be resolved in a cost-effective manner. Lack of adequate solutions for perceived tillage problems may obstruct adoption. Shifts of weed communities, with particular regard to annual and perennial grass weeds, are strongly perceived by farmers as a key problem.[201] However, whether this turns out to be the case is determined by the entire farming system and not by tillage alone. Therefore, tillage practices must be considered only in the context of the whole farming system. The ranking of a weed infestation in a farmer's view is highly dependent on available technologies to tackle weeds successfully, his or her socio-economic environment, and, more importantly, the economic outcome of the farming business. A large set of effective weed-control technologies, both direct and indirect, provide a basis for successful weed management, including cover crop as a successful weed-suppression tool (see, for example, References 79, 202, and 203). Tuned and balanced farming components aiming at sustaining farm income while minimizing risk of environmental pollution characterizes the integrated farming system that has been established in Europe in recent decades.[104,106,204] The components that are considered significant in designing weed control strategies in conservation tillage systems are discussed in the following subsections.

6.6.3 Crop Rotation and Cropping System

Due to the significant effects of crop rotation on weeds, it is essential to avoid risky crop sequences in noninversion-tillage approaches. Winter cereals dominating rotations comprise the higher risk compared to crop diversified rotations.[51,205] A break crop is likely to mitigate weed pressure compared to continuous monocultures.[52,140] The domination of a single crop species over a long time scale is likely to exert higher selection pressure on the present weed community, resulting in high incidence of competitive species. Conservation tillage requires complementary precautions to avoid an increase in weed problems. Fallows provide practical multigoal options with weed-controlling effects such as cover crops or fallow disking. They are feasible only if winter/spring crops are balanced, for example, in temperate zones or crops of different developmental durations in the tropics. Fallow as a time window is likely to reduce dependency on herbicides for weed control. Crop-free periods may be

prolonged by delaying drilling of the following *winter* crop or by choosing varieties with late drilling features. Some winter wheat varieties may be sown even very late in the season. As a consequence, crop rotations in noninversion-tillage systems should be balanced between cereals and broad-leaved crops as well as between winter- and spring-sown crops, taking into account the phenology of prevailing weed species. The nonplowing approach has the potential to maintain yields and suppress some diseases (see Chapter 7).[206]

6.6.3.1 Fertilization Regime

Fertilizer supply is commonly determined by the specific crop nutrient requirements for the targeted yield potential. Partitioning of the nutrient supply depends mainly on the crop uptake pattern and nutrient availability in the soil solution. A considerable part of the crop requirements is supplied from the pools within the soil already, for example, the mineralization of organic reserves. If tillage-based alternations in the mineralization pattern at a given site are intended to restrict weed growth, then they require system-adjusted nutrient management, taking into account both temporal and spatial distribution of fertilizers. Band application of fertilizers in row crops exerts adverse effects on weed biomass.

6.6.3.2 Mechanical Weeding

There are no mechanical weed-control methods adapted only to noninversion tillage. Harrowing, hoeing, and similar technologies are also applicable to conventional-tillage systems. The only difference concerns the no-tillage system, which abandons all mechanical disturbance to soil except for seed farrows. Despite various promising efforts,[207,208] mechanical weed control has still not been widely adopted. Unless cost-effective technologies emerge and control efficacy improves, large farms can hardly adopt such techniques, for the following reasons:

- Higher labor demands and costs
- Limited working speed
- Unavoidable mechanical crop injury builds an operational risk
- Limited weather windows to complete the operations
- Regrowing or spreading risk of some perennial species

Mechanical, thermal, or solar weed-control options may provide a valuable supplement to pure chemical weed control in integrated farming approaches. As with mechanical means, they are still insufficiently developed to be widely used in arable agriculture. In restricted cases, they may provide an alternative to herbicide treatment, i.e., at low infestation levels or dry weather conditions.

6.6.3.3 Cover Crops and Green Manures

Green manures provide effective ways to suppress weed growth and limit or even prevent weed shedding. They can be established even within no-tillage systems.[76,202,209] Catch crops not only suppress weeds but also minimize nitrate leaching

into groundwater. They have repeatedly been reported to enhance numerous groups of soil fauna.[210] Mulching of cover crops at preblossoming times prevents both the shedding of weed seeds and the addition to the soil seed bank. In this function, cover crops support the seed-depletion strategy advocated for weed control.[211–213] Depleting seed stocks in the topsoil while preventing dormant seeds in subsoil layers from germinating would support an overall weed-management strategy. Several cuts of clover grass (hay or silage) as practiced in Switzerland are also likely to prevent weeds from maturing and replenishing the soil seed bank. The hay-making option is reported to deplete the storage of assimilates in rhizome of perennial weed species.

6.6.3.4 Chemical Control

Chemical weed control in noninversion-tillage systems is even more important than in most other current tillage systems. This is particularly true for no-tillage systems.[53,99,118,214] It is beyond the scope of this chapter to review the available chemicals or provide herbicide-based control concepts. However, it should be emphasized that the herbicide option is a very significant component in weed-management strategies in noninversion-tillage systems. On the other hand, a higher weed infestation does not necessarily enforce higher herbicide inputs, and it cannot be attributed to tillage regime alone. The higher incidence of grass weeds under no-till conditions tends to impose a dependence on some classes of herbicides but not necessarily on higher treatment frequency. Often, it was the timing of treatments, rather than the weed regrowth or regermination, that necessitated additional herbicide treatments. Studies that showed higher herbicide needs were based on somewhat short observation periods after adoption of the alternative tillage regime. Unless a permanent increase of problem weed species—under exclusion of other suppressive husbandry measures—is predicted, conservation-tillage systems are unlikely to alter treatment intensity. Long-term studies preferentially conducted under commercial farming conditions would highlight actual tillage impacts in regard to herbicide use. Based on their long-term trials in the U.K.,[140] the authors suggested that while seed banks increased, weed problems did not increase with noninversion tillage. Based on grass weed control in the broad-leaved break crops and broad-leaved weed control in cereal crops, herbicide input was reduced by 50% compared with the conventionally managed weed-control programs. This strategy has gradually reduced the need for grass weed herbicides (isoproturon) by more than 73% over the 7-course rotation.

Besides the aforementioned strategy, there are a large number of further options to reduce herbicide inputs under no-till environments. Minimizing treated areas, using low-volume spray options, combining herbicides with adjuvants, or applying low-dose herbicides in combination with mechanical means are reported to provide effective weed control. Due to serious environmental concerns, alternative weed control methods are receiving increasing attention in Europe. At Lautenbach, average herbicide consumption of the integrated framing system (noninversion tillage) was reduced by an average of one third over 17 years and six field units (Figure 6.9)

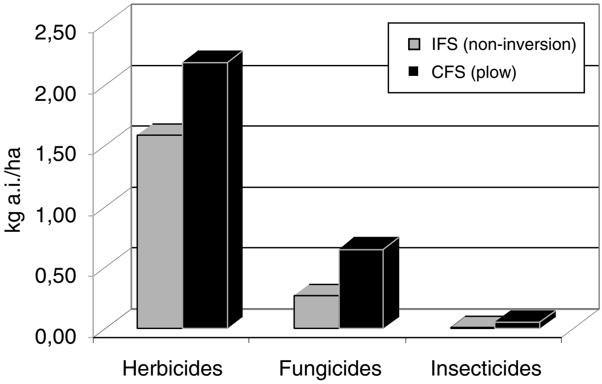

Figure 6.9 Mean pesticide consumption (kg a.i./ha) in integrated (non-inversion tillage) and conventional farming systems (annual plowing) in average of 6 fields each over the period 1978 until 1993 at the commercial farm of Lautenbach/Germany. Comparable active ingredients, applied in the same crop species (winter wheat, spring wheat, spring barley, oats, sugar beet, faba beans/peas and green covers) in both farming systems are the basis for this comparison.

6.7 CONCLUSIONS

Conservation tillage is being increasingly adopted in world agriculture for various reasons. Shifts in weed communities, however, are reported to be a limiting factor for broader adoption. Research results from different climatic zones, crop species, and cultivation systems suggest that the effect of tillage on weed communities is greatly influenced by the associated husbandry practices of the implemented farming system. The wide variation of reduced-tillage systems, ranging from shallow and tine cultivation to the noninversion-tillage approach (conservation tillage), is more commonly associated with grass and perennial weed species than with the counterparts of the plowing technology. By contrast, annual broad-leaved weed species (dicot species) prevailed under the plowing regime (see, for example, Reference 125). Changes in weed communities were found to be influenced more by location, year, and crop rather than by tillage system, especially during the first years following adoption of conservation tillage. Weed community parameters (Shannon H, evenness, species richness and dominance) indicated shifts in diversity indices in some cases, but the trends were not always consistent. Crop rotation and cover crop were proved to produce highly significant effects on the shifts in weed communities. Even simple precautions may contribute to minimizing the weed infestation incidence in fields, for example, through avoiding dispersal by farm machinery.[215,216] Unless the replenishment of soil seed banks is prevented or at least minimized, grass weeds are predicted to increase in numbers. Weeds occurring in densities below the economic threshold may provide beneficial functions in weed–crop interactions. Annual shifts in weed numbers do not necessarily imply the need for higher herbicide use, but this has been suggested in some studies. Long-term farming system studies with noninversion-tillage regimes in the U.K. and Germany

have achieved reductions in herbicide rates of 30 to 50% of the rates used in conventional tillage systems and so demonstrated that noninversion-tillage approaches have a positive effect on the environment, not only with respect to erosion control and nutrient losses but also in regard to pesticide use in arable farming systems.

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